



PROGRAM : BACCALAUREUS TECHNOLOGIAE
ENGINEERING METALLURGY

SUBJECT : **PHYSICAL METALLURGY IV**

CODE : **PMY43-2**

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JULY 2014

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TOTAL MARKS : 167

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INSTRUCTIONS : QUESTION PAPERS MUST BE HANDED IN.

REQUIREMENTS : NONE

INSTRUCTIONS TO CANDIDATES:

PLEASE ANSWER ALL THE QUESTIONS.

QUESTION 1

1.1 Differentiate between random substitutional solid solutions and short-range ordered substitutional solid solutions. Elaborate. [12]

1.2 During the solidification of an Al-2 wt% Cu alloy melt, the Cu concentration in the solid phase was found to be twice the equilibrium concentration expected from the phase diagram. One explanation could be that the fraction of vacancies in the solid exceeds the equilibrium value and that the interaction between vacancies and Cu atoms enhance the solubility of Cu in the melt. The regular solid solution model is supposed to be valid. Estimate the regular solution parameter $\Omega_{\text{Cu/vac}}$ between vacancies and Cu atoms in the Al matrix with the aid of the following data. Derive the significance of your result. [14]

The solidification of the alloy started at 657 °C. At this temperature, the concentration of vacancies in the alloy was $X_v = 3.2 \times 10^{-3}$ (mol fraction). The free energy of formation of vacancies in Al matrix is $\Delta G_{\text{vac}} = 75.3 \text{ kJ mol}^{-1}$. The partition coefficient of Cu solute between the liquid and solid phase as a function of the vacancy concentration in the solid phase is:

$$k_{\text{vac}} = X_{\text{Cu}}^{\text{S}} / X_{\text{Cu}}^{\text{L}} = k_{\text{vac}}^{\text{eq}} \exp [-(X_{\text{vac}} - X_{\text{vac}}^{\text{eq}}) (\Delta G_{\text{vac}} + \Omega_{\text{Cu/vac}}) / RT], \text{ with } k_{\text{vac}}^{\text{eq}} = X_{\text{Cu}}^{\text{eq S}} / X_{\text{Cu}}^{\text{eq L}}$$

1.3 At 1160 °C, ferrite is less stable than austenite by 74 J mol^{-1} . However, at this temperature it can be possible to stabilize ferrite with regard to austenite if 6 at % Si is added in the steel composition. Estimate how much Si is required to keep a ferrite microstructure up to 1160 °C if this steel has to also contain 0.8 at % Ni. The distribution coefficient of Ni between austenite and ferrite is 1.3. [12]

(38)**QUESTION 2**

2.1 Discuss the similarities between high-angle grain boundaries and incoherent interfaces and derive the atomic mechanism of their migration. [10]

2.2 Describe the origin of recrystallization texture in a material. [8]

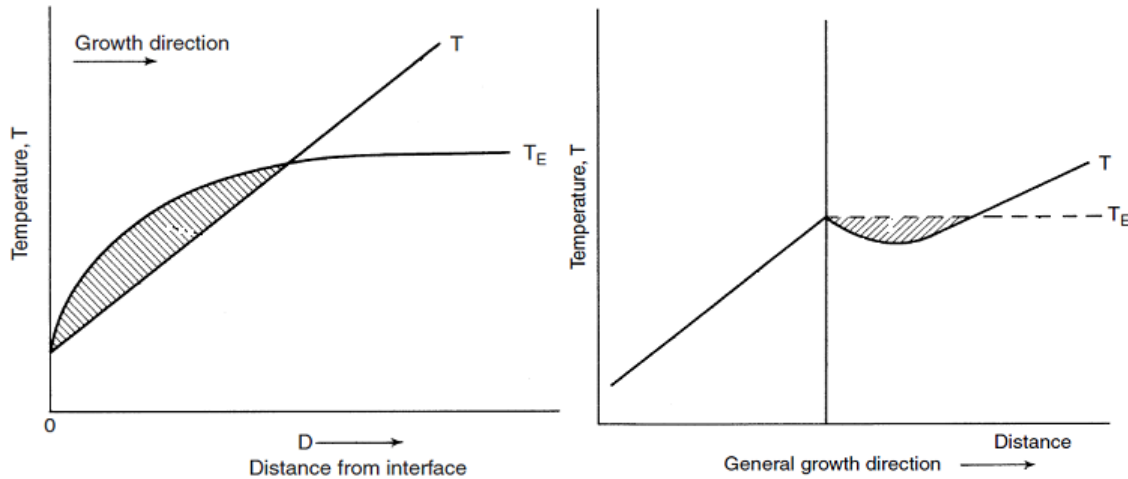
2.3 Give two applications where recrystallization texture is exploited. [4]

2.4 Advice on a recommendation that could help avoiding recrystallization texture if not required in a material. [3]

(25)

QUESTION 3

- 3.1 Given the following temperature gradients in the liquid L and solid S relative to the migration of a S/L interface during solidification and the associated equilibrium temperature T_E . Name the hatched zones and elaborate on their origin and significance. [12]



- 3.2 In connection with the solidification of metals and alloys, heterogeneous nucleation only affects the energy barrier of nucleation ΔG^* but not the critical nucleus radius r^* . However, heterogeneous nucleation takes place at smaller undercoolings than homogeneous nucleation. Reconcile these statements. [10]

- 3.3 Elaborate on the microstructure development upon the solidification of an ingot of an off-eutectic alloy, particularly on the formation of so-called divorced eutectics. [16]

(38)**QUESTION 4**

A nickel sample pulled at 10 % elongation was subsequently annealed 10 min (earlier stages of recrystallization) at 425°C. The deformed matrix contained a dislocation density of 10^{16} m^{-2} (i.e. 10^{16} m m^{-3}).

- 4.1 Calculate the pulling force that could be acting on an advancing high-angle boundary during this recrystallization. The dislocations had each an energy of $0.25 \mu\text{b}^2 \text{ J m}^{-1}$. [6]
- 4.2 If the dislocation-free grains grew from spherically shaped nuclei, what was the diameter of the smallest nucleus that could expand into the surrounding deformed matrix? [6]

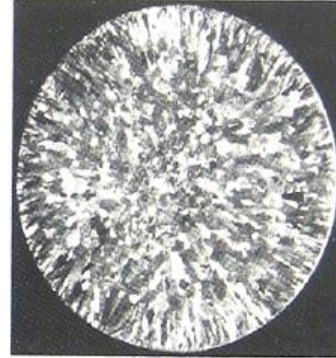
Assume a Burgers vector $b = 0.25 \text{ nm}$ and a high-angle grain boundary energy of 930 mJ m^{-2} .

The shear modulus is $\mu = 7.6 \times 10^{10} \text{ N m}^{-2}$ and the molar volume $V_m = 6.5888 \times 10^{-6} \text{ m}^3 \text{ mol}^{-1}$.

(12)

QUESTION 5

The following figure depicts the macrostructures of the cross section of 10 cm cylindrical castings of the same AA1050 Al-alloy out of identical moulds.



5.1 Differentiate these three macrostructures

[8]

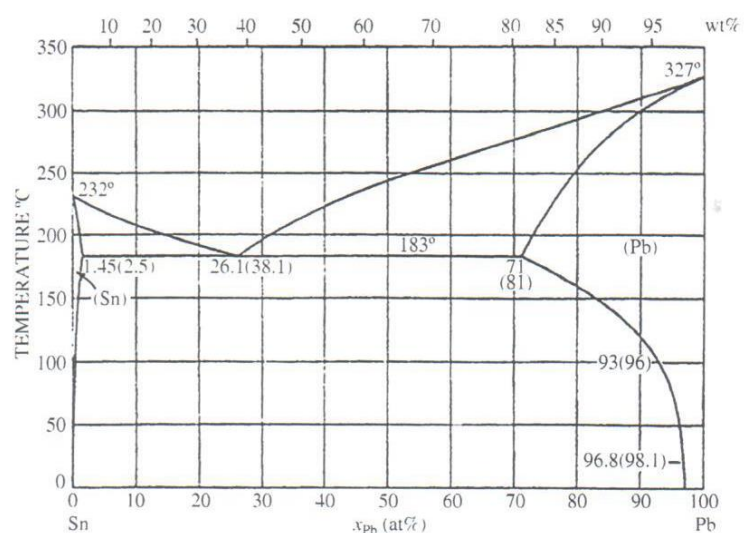
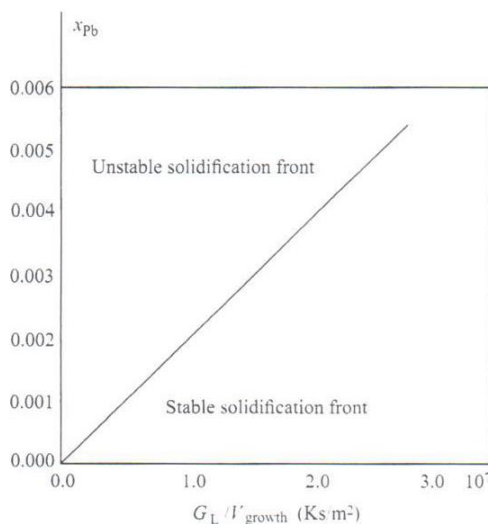
5.2 Elaborate on the parameters used which could help shifting from the first macrostructure to the second one.

[10]

(18)

QUESTION 6

When an Sn-Pb alloy solidifies there may be a transition from a planar solidification front to an unstable front depending on the experiment conditions. The figure below shows that the transition depends both on the alloy's composition x_{Pb} (in [at %]) and on the ratio of the temperature gradient T'_L (here G_L) and growth rate v (in $10^7 \text{ }^\circ\text{K s m}^{-2}$).



With the aid of the figure above mentioned and the phase diagram of the Sn-Pb system, calculate the diffusion coefficient of Pb atoms in Sn-Pb melt.

(15)

QUESTION 7

In connection with the ageing of a supersaturated Al-4 wt % Ag alloy:

7.1 Assuming that the α (Al) matrix is elastically isotropic, both GP zones and matrix have equal elastic moduli and Poisson's ratio is $\frac{1}{3}$, estimate the volume misfit, in-situ or constrained misfit as well as the total elastic (misfit) strain energy ΔG_s of GP zones [6]

7.2 Derive and estimate the critical radius of GP zones for coherency loss. [10]

7.3 Knowing that the grain size of α (Al) grains is approximately 10 μm , which volume fraction f of GP zones should be required in this particular instance to inhibit grain growth? [5]

Assume that the structural free energy γ_{st} introduced at the matrix-GP zone interface upon coherency loss is 3.4 mJ m^{-2} . Atomic radii of Al and Ag are respectively 1.43 and 1.44 \AA . Shear modulus μ of Al = 25 GPa.

(21)

[167]